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A. C. TRUE, Director.

EXCAVATING MACHINERY

USED FOR DIGGING DITCHES AND BUILDING LEVEES.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., May 22, 1907.

Sir: I have the honor to transmit herewith a manuscript on excavating machinery used for digging ditches and building levees, prepared under the direction of Dr. Elwood Mead, Chief of Irrigation and Drainage Investigations, by J. O. Wright, supervising drainage engineer.

The great interest being taken in drainage throughout the whole country makes this subject of especial interest, and it is therefore recommended that this paper be published as a circular of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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EXCAVATING MACHINERY USED FOR DIGGING DITCHES AND BUILDING LEVEES.

INTRODUCTION.

In the early settlement of this country ditches were dug with spade and shovel and the earth was cast out on the side. If the channel was large the earth had to be rehandled and in some instances was carried out in baskets or in hand barrows. At a later day the earth was excavated with pick and shovel, placed on a wheelbarrow, and conveyed to the spoil bank. Even this method is both slow and expensive and is not adequate to the needs of the present time. Much ditching has also been done with team and scraper where conditions permit. The earth is loosened with a plow and removed with either drag or wheel scrapers of some kind. For a shallow ditch in dry ground this is a very satisfactory way of doing the work, but for a deep ditch or in soft ground it is too expensive and in many places wholly impracticable.

Owing to recent economic changes, whereby manual labor has been in a great measure supplemented by skill, it is impossible to carry on large works of any kind without the aid of machinery. This condition has stimulated inventors and manufacturers and great progress has been made in the construction of machinery to take the place of manual labor in almost all lines of work. In no case has this been more marked than in the application of machinery to the digging of ditches and the building of levees.

KINDS OF DITCHES TO BE CONSTRUCTED.

In the reclamation of wet lands by drainage it is necessary to construct three kinds of ditches: (1) Large mains or outlet channels; (2) open laterals or branch ditches; and (3) tile drains.

These several kinds of ditches are all for the purpose of drainage, but the character of the land and the conditions under which they are usually excavated require that their construction be carried on in different ways.

The mains are large open channels, varying in width from 30 to 300 feet and in depth from 3 to 20 feet, and are designed to carry off the surface water after a heavy rainfall and to afford an outlet for the laterals and tile drains. Where the country is at all undulating these

mains follow the general courses of the small streams or natural waterways which are usually improved by widening, deepening, and straightening, so as to provide the required capacity; but through extensive level areas it is frequently necessary to construct new channels to serve as outlets for general drainage systems. There is usually an excess of water where these channels are located, and it has been found impracticable or too expensive to construct them with spade and wheelbarrow or with team and scraper. In digging ditches of this kind by hand labor it is difficult to get the necessary depth to drain the land because of the inflowing water. If water does not cover the land it is usually found very near the surface, so that work of this kind can be successfully carried on only during the driest part of the year.

Before the introduction of machinery works of great magnitude were rarely undertaken and almost never completed. In many of the States having large areas of wet land, particularly in the Middle West, extensive surveys were made for drainage systems and the construction was undertaken; but usually it was found to be impracticable to complete the work where the ditches were deep or a large amount of earth was to be removed, because of the water encountered and the heavy cost of doing such work by hand.

In 1882, under the general drainage law of Illinois, a large drainage district was organized in Mason and Tazewell counties, and a dredge boat was used for excavating the ditches in this district. This was probably the first successful attempt made in the United States to excavate a drainage ditch by means of machinery. The work was attended by many delays and difficulties and much time and money were spent in perfecting the details of the machine used, but the principle employed was correct, and since that date various manufacturers have designed and built ditching dredges of different types until the market is now fairly well supplied with suitable machinery for constructing almost any kind of large ditch.

Small ditches are still excavated by hand or with team and scraper.

CLASSES OF DREDGES.

In order that the operation of ditching dredges may be understood and the type of machine best suited for any particular kind of work selected, it will be well to classify them and point out the most essential features of their construction.

The term "dredge" or "dredge boat" is commonly applied to any steam excavator used for handling earth other than the steam shovel used by railroads. The latter is an excavator mounted on trucks which run on the railroad track; being self-propelling it is readily transported from place to place along the line of the road. It is used almost exclusively for loading earth into cars. Its machinery is sim-

ilar to that of a dredge boat, but its short reach and narrow base render it unfit for ditching purposes.

Dredges may be classified as to the way in which they are moved along on their work as (1) floating dredges, (2) traction dredges, (3) roller dredges, (4) drag boats, and (5) walking dredges.

Dredges are also classified as to the method of handling the material, as (1) dipper dredges, (2) clamshell or orange-peel dredges, (3) scraper dredges, (4) elevator or bucket dredges, and (5) hydraulic dredges.

A further classification is made by the manufacturers and users of dredges, based on the size of the bucket used in handling the material. If the bucket or scoop holds 1 cubic yard, it is spoken of as a 1-yard dredge; if it holds 2 cubic yards, a 2-yard dredge, and so on, the size being designated by the size of the bucket used.

DIPPER DREDGES.

The oldest and best-known type of dredge and the one most used for drainage ditches is the ordinary dipper dredge (fig. 1). This machine

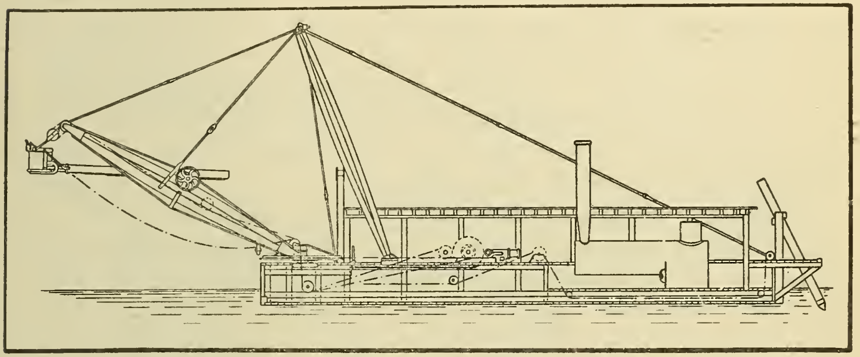

FIG. 1.—Dipper dredge, side view, showing arrangement of machinery.

is built with capacities ranging from ½ yard to 3 or 4 yards, and is suited for any kind of work in which there is sufficient water to float the machine. For ordinary dredge ditches a 1-yard or 1½-yard machine is considered most economical, and is generally used.

The essential parts of a dipper dredge are the hull or platform, engine, boiler, A-frame, swinging device, spuds, boom, and dipper. These are used in some form on all dredges for ditching purposes. Each manufacturer varies the details of construction and claims certain points of superiority, but the general principles are the same throughout.

HULL.

The hull is usually built of wood, and its dimensions depend upon the width of the ditch to be constructed and the size of machinery to be used. There is a proper relation that must exist between the

size of the hull and the other parts of the dredge, and if this is not observed the dredge will draw too much water, be top-heavy, or cumbersome and unwieldy. Where the ditch to be constructed is narrow—20 to 30 feet top width—a small machine—that is, one with a dipper holding 1 cubic yard or less—is best suited for the work. The engine and boiler for such a dredge are comparatively light, and can be carried on a hull 18 feet wide, 54 feet long, and 5 or 5½ feet deep. Although a dredge with a narrow hull can be successfully operated, it is better to make it as wide as the conditions will permit. For a 1½-yard or 2-yard machine the hull should be 26 to 40 feet wide, according to the length of boom to be used, and its length should be two and one-half times its width. This is necessary in order to counterbalance the weight of the boom and dipper when discharging the load.

When the dredge is at work the hull is subjected to a combination of strains that severely taxes its strength, so it must be well designed and substantially built or it will fall to pieces. For ditch work the hull is usually made of a framework of timbers planked on the bottom and sides with 3-inch planks, or the sides may be made of heavy timbers placed one on another and bolted together. In either case it should be strengthened by numerous bulkheads or trusses running fore and aft to prevent buckling or hogging in the middle. It is a great advantage in a hull to have as long timbers as can be secured and to break joints in their arrangement.

In the early practice of dredge building some manufacturers thought it advisable to build the hull wider on the top than on the bottom, giving the sides a slight slope to more nearly conform to the sides of the ditch, but this was found to be of no material advantage and was discontinued. The common practice now is to build the hull the same width both top and bottom (fig. 2). A point that should receive special attention in the building of a dredge hull is to see that it is well caulked, as when it is in the water and the machinery installed it is impossible to repair or replace poor caulking. The bottom and sides should be at least 3 inches thick, so jointed as to make a close seam on the inside and so outgaged as to make a seam one-eighth inch on the outside. The caulking should consist of three threads of clean oakum driven firmly into the seam and finished smooth one-half inch below the surface. Seagoing dredges have their decks caulked, but this is not necessary for ditching purposes. Where the dredge is to be towed a great distance in open water there is some advantage in having a false rake on the stern.

In most cases drainage systems are widely separated and are not connected by navigable streams. Consequently, in order to move the dredge from one district to another it is necessary to take it to pieces. This practically destroys the hull, and in many instances it is cheaper

to build a new one than to move and rebuild the old. To save this expense many attempts have been made to construct a hull in sections, so that it can be more readily taken apart and transported on cars, but this method has many serious objections and is not looked upon with favor.

In placing machinery on the hull there are two methods in vogue. One is to deck the hull over and place all the machinery above deck. The other is to place the heavier pieces below deck. Each of these plans has some points in its favor. For a large, heavy hull with a broad beam it serves the purpose just as well and is more convenient to have all the machinery on deck, but on a narrow hull of light construction it is better to have the heavy machinery below the deck, as it lowers the center of gravity and adds to the stability of the boat.

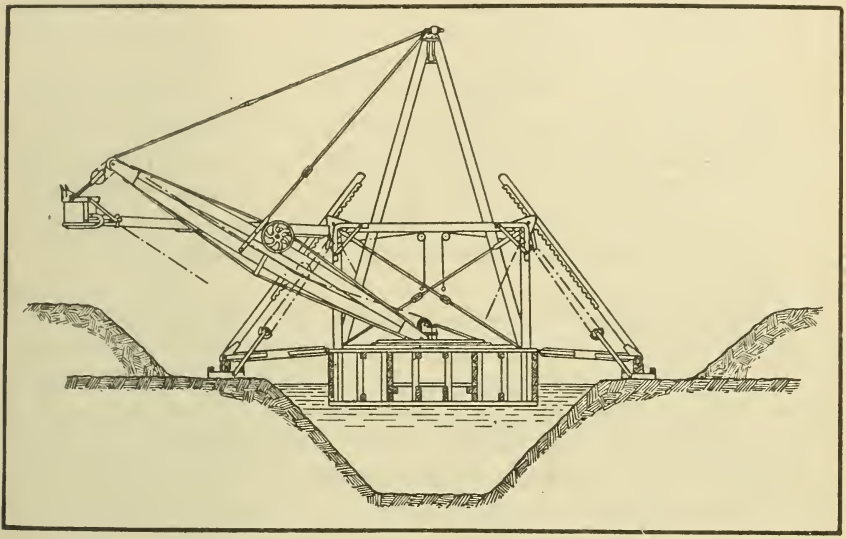

FIG. 2.—Dipper dredge, end view, with bank spuds.

A most excellent plan is to put in a foundation for the engine and boiler about midway between the top and bottom and place the swinging device and boom seat on the upper deck near the front. This plan seems to be best for a dredge for ditching purposes and is the one most generally followed.

ENGINES.

The best engine for a dredge is some type of a horizontal, double-cylinder, friction-drum engine, self-contained on a cast or structural-iron bed plate. Each manufacturer has his own design, differing from the others only in details of construction, material, and workmanship. There are good engines and bad engines of the same rated horsepower, and a prospective purchaser, if not an expert, should

require a guaranty of not only the performance but the durability of the engine he purchases. The best dredge engine has steel gear and extra large shaft and wrist pins as compared with engines of the same horsepower designed for other purposes where the work is more uniform. There is no service in which the shock caused by throwing on and off the load is more severe than in dredging, and unless the engine is very thoroughly built constant breaks, causing delay and expense, are sure to occur.

Dredge engines are designated by the dimensions of their cylinders rather than the horsepower developed under certain conditions. The following sizes have been found from experience to be best suited for dredges of different capacities: ½-yard machine, 6-inch diameter by 8-inch stroke; ¾-yard machine, 7-inch diameter by 10-inch stroke; 1-yard machine, 8-inch diameter by 10-inch stroke; 1½-yard machine, 10-inch diameter by 12-inch stroke; 2-yard machine, 12-inch diameter by 16-inch stroke, or their equivalents in cylinder capacity.

Dredge engines are controlled by the throttle, and should not be run at a high speed; hence, small bore and long stroke are preferable.

To operate the bucket on a dipper dredge two friction drums, one called the hoisting and the other the backing drum, are necessary. These are generally placed one in front of the other on the bed plate, and are geared to the engine shaft in a ratio somewhere between 1 to 3 and 1 to 6.

One of the most serious annoyances in operating a dredge is the heating and sticking of the frictions. This is due not so much to the material used in constructing the frictions as to an inadequate friction surface. Hard, maplewood blocks or vulcanized fiber working against an iron surface have been found to be the most satisfactory materials for frictions and when properly designed give no trouble. The different manufacturers lay great stress on the type of friction employed, but experience has demonstrated that much more depends on the relative diameters of the friction and the barrel of the drum than on the form of friction employed. Where the diameter of the friction is two and one-half or three times that of the barrel of the drum there is little likelihood of its heating enough to become troublesome in ordinary operation.

BOILERS.

On account of the cost of fuel, the difficulty in getting it on board the dredge, and the impure and muddy water that has to be used in most places the size and type of boiler are of the utmost importance to the user of a dredge. The cheapest boiler and the one most commonly used is of the locomotive firebox type, with either open or water bottom. This boiler will burn either wood or coal, and is easily cleaned. A boiler of the Clyde Marine or Scotch Marine style is more

economical in use of fuel, more durable, and is the safest boiler that can be used, but it is more expensive, especially in the smaller sizes, and is, therefore, not much used on small ditching dredges, although on a large job the saving in fuel will more than repay its extra cost. A vertical boiler or a brick set boiler is wholly unsuited for dredge work. Any boiler, whatever the type, should be thoroughly inspected and tested to 150 pounds hydrostatic pressure before being put into service.

Not only the style but the size of the boiler should be carefully considered, as this has much to do with its durability and efficiency. The horsepower is computed according to established rules from its heating surface, and usually the rated horsepower can be developed only under the most favorable conditions, which are rarely found in a swamp or on an open dredge boat. If it requires the full capacity of the boiler to operate the machinery under ordinary conditions, at times, when the fuel is poor, the water foams, or the atmosphere is heavy, the required pressure can not be maintained and much time will be lost owing to the lack of sufficient steam to do the work. Further than this, if it is necessary to crowd the boiler in order to furnish steam it will not last nearly so long as it would if it possessed some reserve capacity. For these reasons it is better, in choosing a boiler, to select one having a rated horsepower at least 25 per cent greater than is required to operate the engines. The improved service and the increased life of the boiler will more than compensate for the additional cost.

A dredge boiler should be provided with the usual fittings, including 24 feet of stack, and should have two separate and distinct boiler feeds, whether they be injectors or pumps. On many ditches it is necessary to use foul water and much time will be saved by having these two independent feeds. In a cold climate economy of fuel is effected by covering the boiler and steam pipes with some good boiler covering.

A-FRAME.

On the deck of the hull near the front a tower called the A-frame is erected. It consists of either two or four members joined at the top and secured with suitable ironwork provided with a gudgeon and crosstree from which the point of the boom is suspended. When the tower has four legs the front two are erected in a vertical plane and the others serve as back braces to hold them in position. Where but two members are used they are inclined forward about 1 foot in 6 from a vertical plane. This arrangement allows greater sweep to the boom and is the one most used. In either method the top of the A-frame must be securely stayed by guy rods extending to the sides of the hull. The strength of these guys and the method of their attachment are of the utmost importance, as a failure might endanger the life of the employees on the dredge, besides causing a money loss of many hundred dollars.

In designing and erecting a dredge this point should receive special consideration. The A-frame should be about as high as the point of the boom when it is in proper position for operation. It may be made of wood or iron, but should have sufficient strength to withstand the unequal and sudden jars to which it is subjected without danger of failure.

SWINGING DEVICE.

Dredge builders have done much experimenting on the means of swinging the boom from side to side, but they are not yet agreed on any one method. This is important in the operation of a dredge, as the ease and rapidity with which the boom can be swung has a great bearing on the output of the machine. The heel of the boom sits in a cast socket that rotates on a gudgeon and the point is suspended from the top of the A-frame. The means of swinging it from side to side is either some form of engine and turntable or a "gravity swing." Swinging engines may be independent or power may be transmitted from the main engine to drive suitable swinging drums. When power is taken from the main engine two independent friction drums are attached to its bedplate and geared so as to be driven by it. A chain or wire rope is led from one of these drums around the turntable to the other, so that by setting up one friction and releasing the other the boom may be swung to either side at will without reversing the engines. This method of swinging the boom has been tried by most dredge manufacturers and has some points in its favor. It is cheaper in construction, as the two additional drums for swinging do not cost as much as an independent engine with suitable drums and there is but one engine to keep in order, but the service is not so satisfactory. It is necessary to run the large hoisting engine to swing the boom after the dipper is raised to the required height and also while it is being lowered into the pit. This not only requires more steam, but retards the operation of the dredge. Another objection to this plan is the difficulty in keeping the swinging chain or cable taut. The momentum of the loose drum frequently causes it to pay out cable after the boom has come to rest. Time is lost in taking up this slack, and the boom is started with a jerk, which is objectionable. In any method employed both ends of the swinging cable should remain taut at all times. By using a pair of reversible swinging engines geared to a shaft carrying either one or two fixed drums, this can be accomplished. One end of the chain winds from the top and the other from the bottom of the drums, so that the chain is taken up by one drum as fast as it is released from the other. The main hoisting engine can be shut off when the load is raised to the required height and the swinging engine need be run only when it is desired to swing the boom, thus effecting economy in operation that is not possible with one pair of engines. Practically

all the manufacturers now use independent swinging engines on their larger machines and the practice is growing in favor. The best type of a swinging engine is one having reversing links and throttle connected in such a way that one lever controls all the movements of the engine.

The turntable may be either movable or fixed and can be placed on deck or overhead (fig. 3). For a short boom 45 feet or under a movable turntable—that is, one that rotates with the boom—seems to be the best suited for the work, while for a boom over 45 feet long a fixed turntable gives the best satisfaction. For ease of operation the diameter of the turntable should be not less than one-fifth the horizontal reach of the boom, and it should be attached so as to get as square a pull as possible. A movable or rotating table, often called a "bull wheel," is composed of a rim and spokes attached to the boom seat or hub and

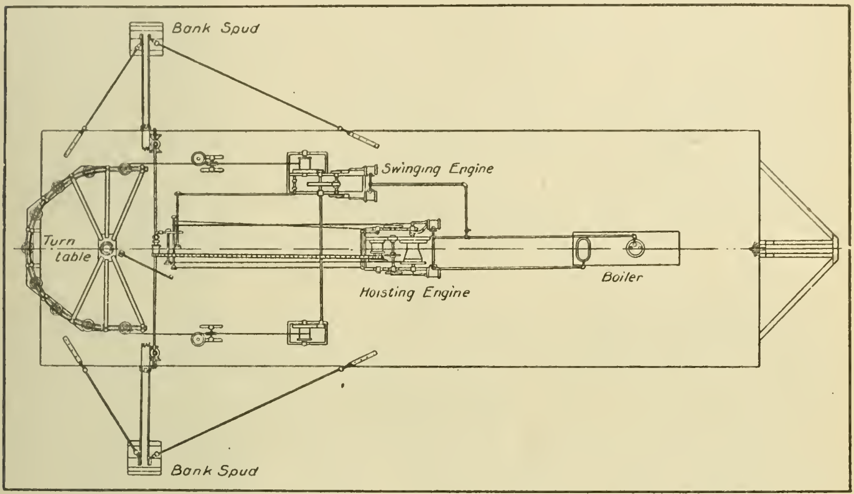

Fig. 3.—Plan of dredge, with stationary turntable and independent swinging engine.

rotates with the swinging of the boom. The outer rim of the circle at opposite points is attached by suitable braces to the boom at about one-fourth its length from the base, and by rotating the circle the power is transmitted to the boom. The rim of the circle and the points of attachment to the boom not being in the same plane, causes the outer edge of the circle to be lifted or depressed by the movements of the boom, resulting in a loss of power and a wrenching of the circle which is hard to overcome. This is one of the reasons why it is difficult to build a movable turntable of large diameter. To overcome this tendency of the circle to twist and warp, some builders erect a mast that rotates and construct the circle around this as an axis 8 or 10 feet above the deck. In this case the point of attachment of the braces to the boom can be in the same plane as the rim of the circle, thus exerting a direct pull. There are two objections to this plan.

It increases the weight above the deck, which tends to make the dredge top-heavy, especially on a narrow hull; and it requires a series of sheaves with heavy framework to lead the swinging chains or cables from the drums to the circle.

A stationary swinging circle is constructed of suitable material and is firmly fastened to the deck or to a framework overhead so that the axis of the circle on which the boom swings passes through its center. The swinging chain leads from the drums around this circle and moves freely on small sheaves. Since the circumference of the circle is attached at several points to the boat, there is no difficulty in holding it in position, so it may be of any diameter required. The power is applied to the boom in the following manner: A swinging timber is pivoted at one end to the dredge in the line of the axis about which the boom rotates and extends either horizontally or obliquely across the circumference of the circle through the center of the boom. Where this swinging timber crosses the circumference it is fastened to the swinging chain. By driving this chain in either direction it moves on the circular row of sheaves, carrying the boom with it, while the turntable remains in a fixed position. This is the best method of swinging a boom 45 to 70 feet long on a dipper dredge. In whatever method used the details should be carefully worked out and the power applied as far away from the base of the boom as is practicable.

SPUDS.

The spuds are three in number and are used to hold the dredge in position while in operation. One is placed on each side near the front and the third in the middle of the boat at the stern. The side spuds are either vertical or bank. For a ditching dredge with a narrow hull bank spuds are more desirable, as they present a broader base and the footings are usually on solid ground. This is quite an advantage, as it permits the use of a much longer boom than could otherwise be used on a narrow boat. Where the channel to be constructed is wide and deep and the banks irregular in height, vertical spuds are more convenient, as they can be used in any depth of water up to 50 feet. The rear spud is a vertical one and is used to prevent the stern of the boat from swinging from side to side as the dredge is operated. The spuds are raised and lowered by chains or wire ropes leading from the spuds over suitable sheaves to spud drums connected with the engine, or by means of a steam cylinder placed in front of each spud, having a movable clamp or shoe encircling the spud and attached to the piston of the cylinder. The latter method is frequently used on large dredges, but is expensive, troublesome to operate, wasteful of steam, and has nothing to recommend it, while a proper arrangement of the wire rope and friction drum has been found to be entirely satisfactory. An important feature of any spud is the locking device for so fasten-

ing it to the spud frame as to hold the boat in position as the boom is swung from the center to the side. Most manufacturers have some special arrangement for this purpose, usually consisting of a heavy cast rack bolted to the spud which engages a dog or pinion attached to the frame of the boat. Whatever device is used, it must be absolutely reliable at all times, so that it will never slip and let the boat upset and sink. The ease and rapidity with which the spuds can be raised and lowered add greatly to the daily output of the dredge.

BOOM.

On a dredge the length of the boom must bear the proper relation to the other parts or it will not operate successfully. Many dredges have failed because this principle had not been observed. In selecting a dredge it is hard to determine what length of boom should be used. Along some parts of the work the channel may be narrow and the excavated material can be placed in equal parts on each side of the ditch, which requires but a short boom, while farther down toward the outlet on the same ditch the channel may be very wide and it may be required to place the excavated material all on one side, which will necessitate the use of a much longer boom. As it is not practicable to vary the hull to suit the different conditions, it is often difficult to decide just what the length of the boom should be.

In practice, on a dipper dredge a boom whose length is one and one-half times the width of the hull has been found to give the best satisfaction; in no case, even with good bank spuds, should its length exceed twice the width of the hull. On a very wide hull the extreme length should never be more than 80 feet. A wooden boom seems to give better satisfaction than a steel one. It is made in two parts, so as to allow the dipper handle to work between them. Lightness and strength are the two essential features in the construction, and the form combining these in the highest degree is most desirable. For a boom less than 50 feet in length a solid construction is preferable, while for a boom 50 feet or longer a truss of some kind has more strength for the weight of material used. As the strain on the boom is not constant, there being heavy jars at times, it, with all its fittings and suspension rods, should be designed with a large factor of safety. The brake shaft should be set a little below the middle of the boom and the pinions on it should be cast steel. The diameter of the brake wheel should be 5 per cent of the length of the boom and the friction band should be lined with leather or wood.

DIPPER AND DIPPER HANDLE.

Working in connection with the boom is a long handle, to the end of which is attached a steel dipper, which loosens the material and

conveys it to the waste bank. The size of dipper varies from one-half to 3 or more cubic yards and is determined by the size and cost of the dredge to be constructed. It requires about the same number of men to operate a small dredge having a capacity of 300 cubic yards per day that it does to operate a large one with a capacity of 2,000 cubic yards, the principal difference in the cost of operation being in the fuel consumed. A large dredge, if properly proportioned, is better able to excavate hard material and to dig stumps and stones than a small one; but a big dipper requires bigger engines and boiler to operate it and a larger hull to carry the machinery. The size of the ditch, the amount and character of the work to be done, and the amount of money that can be invested must determine the size of the dredge to be used. If the machine is to excavate hard material, the dipper should be provided with teeth, but for work in soft material a cutting edge of steel should be put on in their stead. The dipper handle is usually made of straight-grained hard wood, though some manufacturers use steel channels or beams. A wooden handle properly ironed is considered better than a steel one and is most commonly used. The handle on a ditching dredge should be two-thirds as long as the boom, and it should be ironed in the most approved style.

SOME DETAILS OF CONSTRUCTION.

This brief description will give a fair idea of the construction of a dipper dredge. Much depends, however, on the correct proportion of the several parts and the completeness and simplicity of their details. The design should include just as few pieces as can be made to do the work, and they should be strong and substantially formed of the best material. The profitableness of a dredge boat depends largely on its freedom from breakdowns, and the best dredge is the one that will run the most days in the month without stopping for repairs. To assist in securing this, the gears, pinions, and racks should be made of cast steel, and all straps, bands, rods, and bolts of a good quality of iron, preferably Norway. The guys should be provided with turn-buckles for adjusting the tension, and if made of wire rope should have heavy thimbles in all eyes.

Much has been said as to the relative merits of chain and wire rope for use on a dredge. Experience has proved that a steel wire rope is cheaper and gives better satisfaction for hoisting the load than a chain.

The sheaves should be of cast iron with phosphor-bronze or brass bushing. They should be faced and bored true, and all pins should be of steel, neatly turned and fitted to the sheaves. The groove for the wire rope should be at least three times as deep as the diameter of the rope, and the diameter of the sheaves should be not less than 30 diameters of the wire cable to be used on it. Where there is any

probability of the cable getting off the sheaves a substantial housing should be provided to keep it in place.

The cab and roof on a dredge boat are matters of convenience and have nothing to do with its successful operation. They can be designed to furnish such accommodations as may be required. If, however, wood is used as a fuel great care must be taken to have the roof fireproof.

DRAG BOATS.

Machinery of the type described for a dipper dredge has been successfully used for ditching purposes on a drag boat instead of a floating hull.

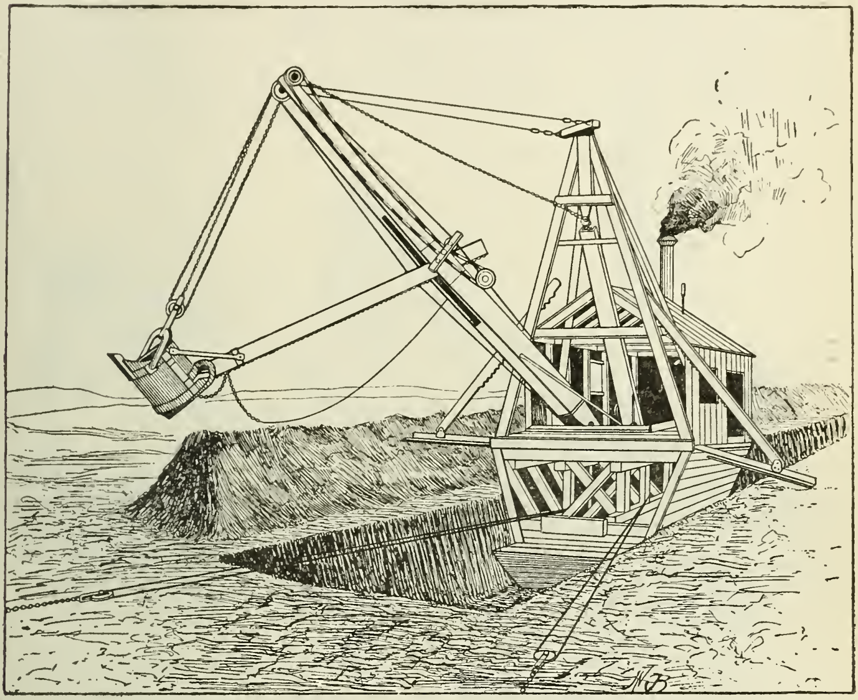

FIG. 4.—Drag boat for cutting dry-land ditches.

Such an arrangement is useful for cutting narrow ditches and for work where there is not water enough to operate a floating dredge. The machinery is mounted on a framework set in the bottom of the ditch, as shown in figure 4, and is moved along on the work by means of a wire cable, one end of which is attached to an anchor ahead of the boat and the other to a cable drum on the boat, driven by the engine. In order to drag a boat in this manner it must be light; a machine of more than three-fourths yard capacity is too heavy for this type of dredge. Where the ground is very soft on the surface it is difficult to set anchors so they will hold, and where there is much sand

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and gravel in the bottom of the ditch the friction is so great that the machine is not easily moved; consequently the use of a drag boat is restricted to a certain kind of work. Where the ditches are narrow, the surface of the ground firm, and the bottom of the ditch free from sand or gravel, it cuts a good ditch and can be operated at a small cost.

CLAMSHELL DREDGES.

Any dredge having a swinging or rotating boom, from the end of which is suspended a bucket by two chains or wire cables, one of which is used to open the bucket and the other to close it, is called a clamshell (fig. 5). The machinery may be mounted on a barge which may float in the pit which it excavates, like the dipper dredge described, in which case it is called a floating dredge; or it may be mounted on a car supported on wheels or trucks that move on a temporary track, in which case it is called a traction or roller dredge (fig. 6).

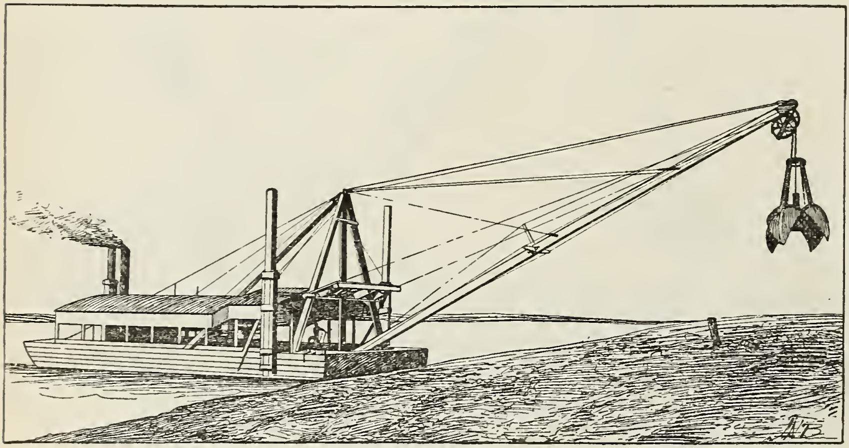

Fig. 5.—Long-boom clamshell dredge suitable for digging large ditches and building levees.

A dredge of this type may be self-propelling or it may be hauled along by a wire rope attached to an anchor ahead and winding on a drum driven by the engines. In operation it usually digs in front and moves back from the finished work, but where the ditch is narrow it might span it and move forward. Since this type of machine has a wide range of uses, its construction will be more fully described.

CAR OR PLATFORM.

The platform of the car may be built of either wood or steel, its dimensions depending on the length of the boom and the size of the machinery to be used. Its width should be about one-third the length of the boom and its length from one and one-half to twice its width. This gives a stable car and one that can be propelled around short

bends. The platform should be mounted on four trucks, one near each corner, each having four wheels 18 to 30 inches in diameter, with a track gauge of 3 to $3\frac{1}{2}$ feet. These trucks move on two parallel tracks, one under each side of the car. This arrangement distributes the weight of the car over a large area, and by placing boards under the track where the ground is soft such a machine can be carried over any ground where a horse can walk. A series of rollers or double-flange wheels are sometimes used under each side of the car instead of the trucks, but this does not distribute the weight so well and the machine can not be propelled around short curves.

The track is of a temporary character, is built in sections, and is taken up in front and relaid behind as the work progresses. Common T-rails, 20 to 60 pounds per yard, are used in this portable track.

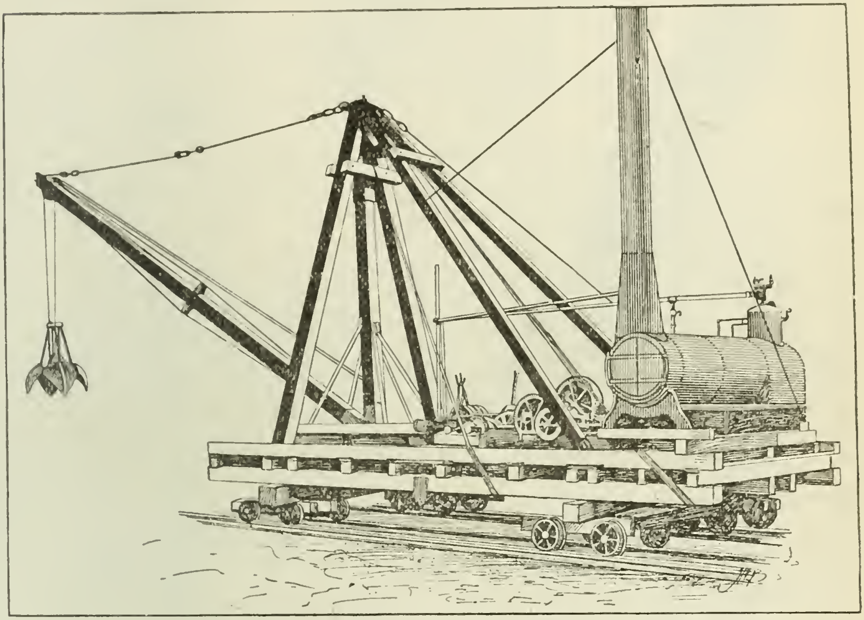

FIG. 6.—Traction dredge (with orange-peel bucket) for dry-land work.

The method of constructing this track so that it may be readily moved and put in place is an important consideration in the operation of the dredge. A wide experience has demonstrated that the plan shown on the accompanying drawing (fig. 7) is the best in use.

The machinery and top work are placed on the platform, as on the deck of a barge, except that the boiler is usually placed crosswise of the platform, at the rear, instead of lengthwise, as on a floating dredge. A traction dredge of this kind, if properly designed, requires no spuds or jack arms to hold it in position.

If it is to be self-propelling, power is obtained from the engine to drive a propelling shaft extending across the car from side to side, and

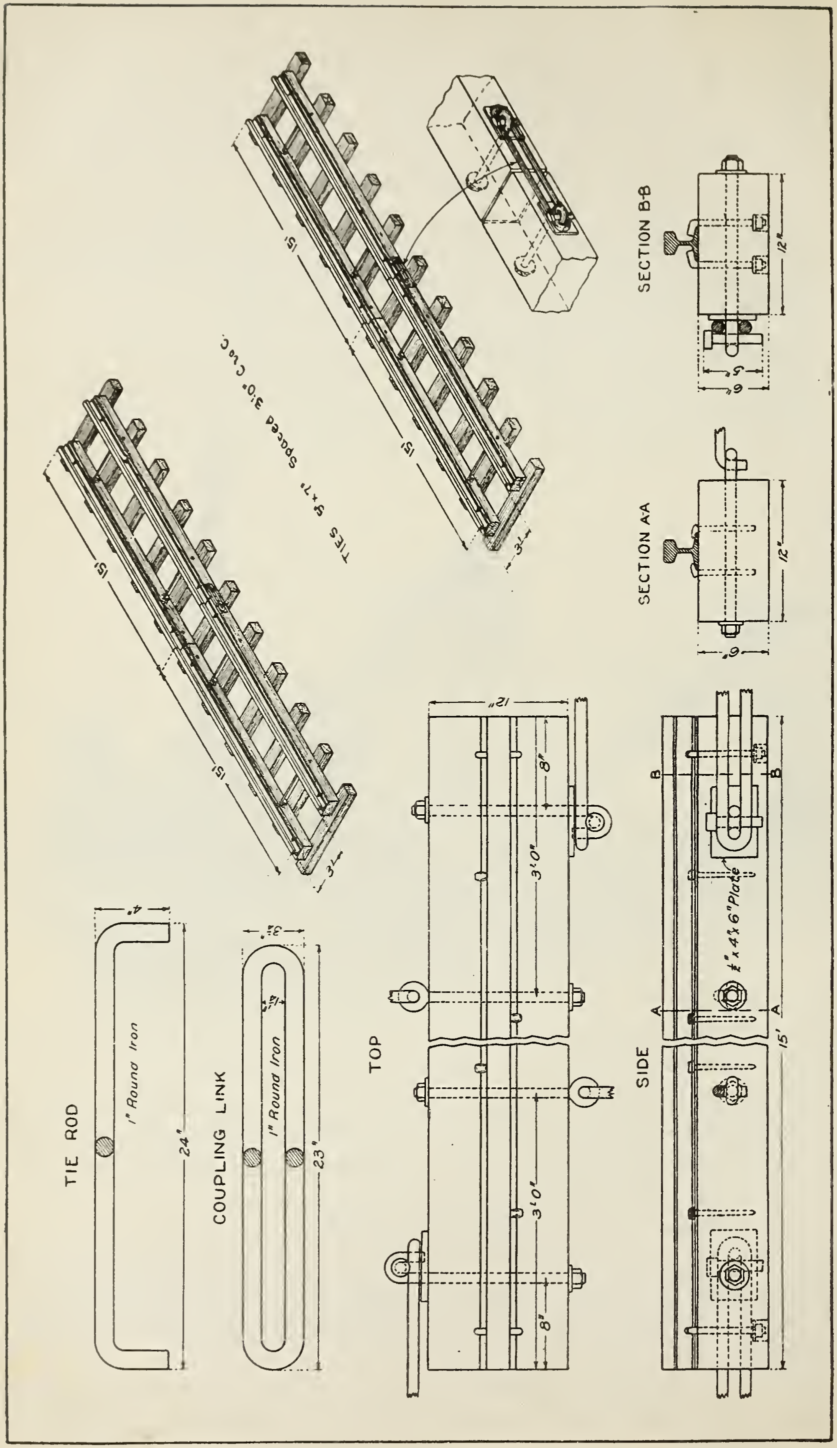

FIG. 7.—Detail drawing showing construction of track for a traction dredge.

usually underneath. On the middle of the axle next this shaft, on each of the four trucks, is fixed a pocket sheave a little smaller in diameter than the wheels of the truck. Two similar pocket sheaves, smaller in diameter, are placed on each end of the propelling shaft, and power to drive the car is transmitted by means of a crane chain from this shaft to each of the four axles. In order to move the car in either direction it is necessary to have engines with reversible-link motion. Such an arrangement has been extensively used and has proved to be efficient, durable, and substantial.

BOOM.

The great advantage of a clamshell over a dipper dredge is the length of the boom that can be used. On a dipper dredge 75 or 80 feet seems to be the extreme length of boom that can be successfully operated, while on a clamshell dredge a boom 120 feet long has been found to do excellent work. This, coupled with the fact that the machine when mounted on a car can dig on one side and place the material excavated on the opposite side, gives it an extremely long reach and makes it desirable for levee building.

The boom on a clamshell dredge may be swung in either of two ways, by a turntable and pair of independent swinging engines, as explained in the description of the dipper dredge, or by what is termed a "gravity" swing. For a boom 60 feet long or under a pair of independent swinging engines and turntable is most desirable, as it gives better control of the machine, but for a boom 60 feet long or over the following method has been found the only successful one. The operating lines that lead from the drums to the bucket are widely separated by sheaves at the front of the boat and the weight of the bucket is transmitted through these lines to the engine drums. When the weight is equal on each line the boom remains still, but when the weight is held on either line the boom swings at once to that side. By changing the weight from one line to the other the boom can be swung in either direction. As the power that really moves the boom is not the engine but the weight of the load, it is called a "gravity" swing. The advantage of this method is that it does away with a turntable and independent engines, and the power or weight being applied at the point of the boom instead of near the hull, it responds readily and is easily held in alignment. After the load is raised to the proper height and while the bucket is being lowered the engines need not run. This effects a great saving in the consumption of steam. On the other hand, the one disadvantage is that the line which closes the bucket must swing it to the dump and the one that opens it return it to the pit, so that the material can be placed on one side only without changing the attachment of the lines on the bucket.

Practically any type of double friction-drum engine can be used on

a clamshell dredge as no backing drum is required, one drum being used to close the bucket and the other to open it, while the two working together may be employed to raise the load.

ROTARY DREDGES.

A rotary dredge is one in which the platform carrying all the machinery, including the boom and dipper, rotates on a gudgeon. This arrangement enables the dipper to describe a complete circle, which is quite an advantage in some places (fig. 8). It is extensively

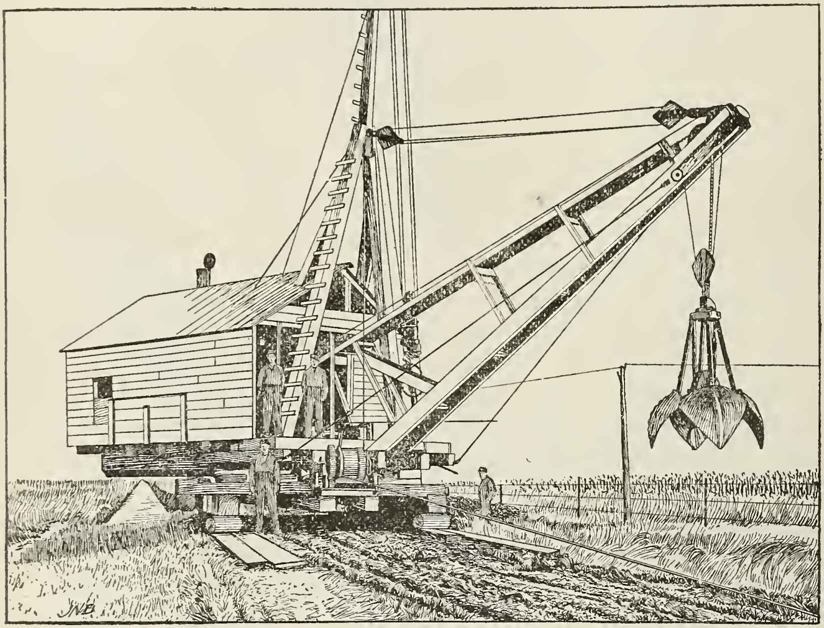

FIG. 8.—Rotary dredge mounted on rollers.

used for handling coal, ore, stone, and other material, and for digging sewer trenches where it is desired to use the material as it is taken out to back fill. It has been tried for ditching purposes, but has no special advantage over the swinging boom and is not likely to come into general use for this purpose.

ROLLER DREDGES.

In order to cheapen the construction many of the land dredges rest on rollers placed between the timbers of the machine and heavy plank laid on the ground instead of on trucks. The machine is moved along on these rollers by a line attached to an anchor and winding on a drum or winch on the machine. This method has nothing to recommend it but cheapness in first cost, and it is slower and more expensive to operate than a well-planned traction machine.

KINDS OF BUCKETS.

On dredges of the clamshell type, whether floating, traction, or rotary, there are various makes of buckets used, all operating on the same principle. If the bucket is formed of two segments it is called

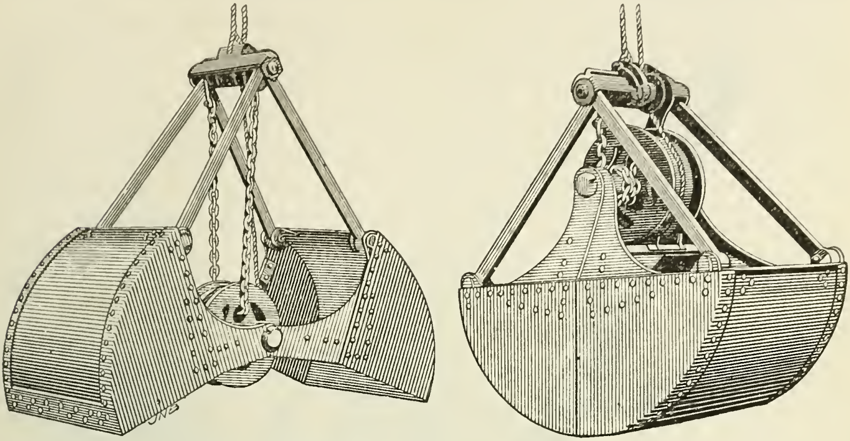

FIG. 9.—Standard clamshell bucket.

a clamshell (see fig. 9), but if made of four segments it is called an orange peel (see fig. 10). The efficiency of the dredge depends largely upon the ability of the bucket to dig the material to be removed, and

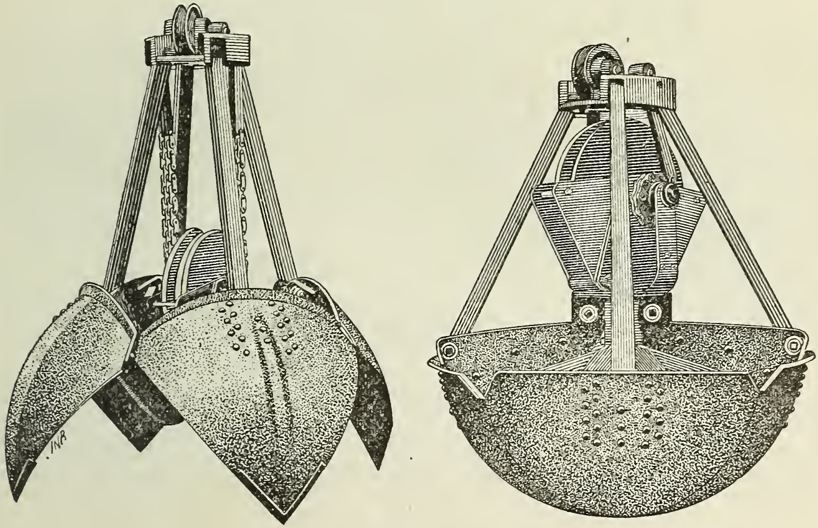

FIG. 10.—Orange-peel bucket.

the lack of a suitable bucket has greatly retarded the use of the clamshell dredge. In soft material any 2-part bucket will fill well, but in

very hard material and where there are many roots and stumps to interfere with its operation, neither the orange peel nor the clamshell is entirely satisfactory. A 2-part bucket fitted with teeth and a compound closing power is probably the most effective bucket for hard clay or quicksand.

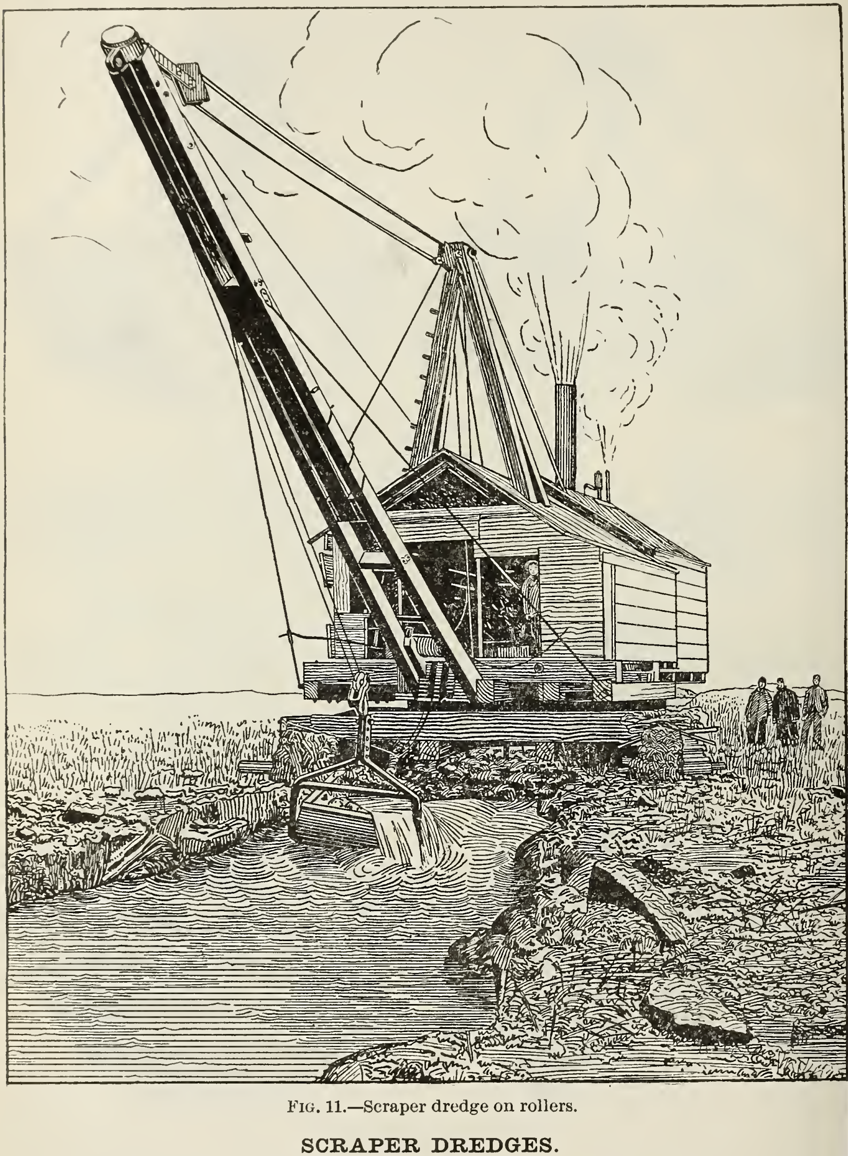

FIG. 11.—Scraper dredge on rollers.

SCRAPER DREDGES.

There are some machines on the market which handle the material with a scoop resembling an ordinary drag scraper. These may aptly be called scraper dredges (fig. 11). One of these is built like a traction

clamshell with a double friction-drum and independent swinging engine. Instead, however, of using the clamshell or orange peel bucket suspended from the end of the boom by two lines, a steel scraper is used. This scraper is suspended from the end of the boom with one of the operating lines attached to the bail, while the other leading from the drum passes over a sheave in the boom near its heel and is attached to the front of the scoop. By this line the scoop is drawn toward the machine when being filled, while the other is used to raise and lower the back end, so that it will have the right inclination to slice the earth away as it is drawn forward. When filled, by keeping both lines taut it can be raised to the point of the boom,

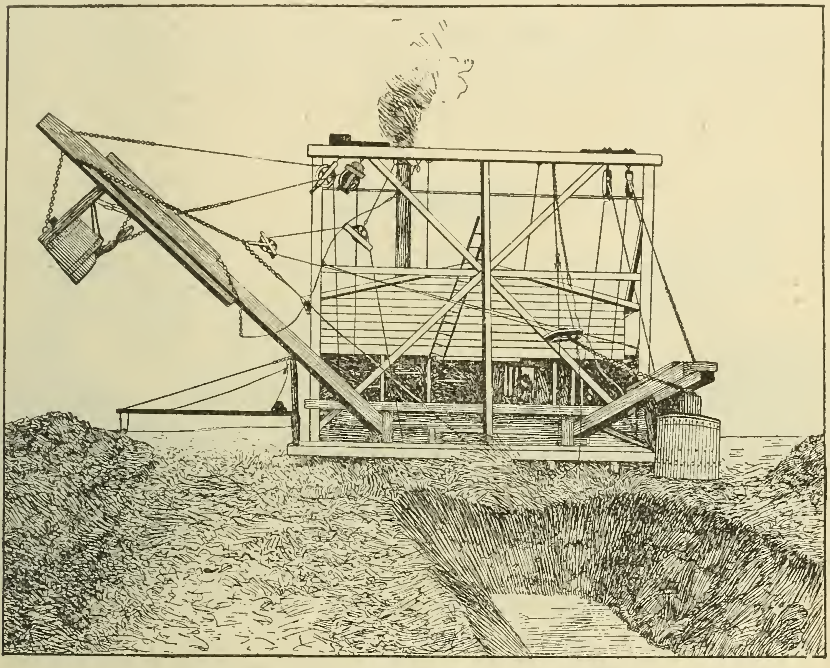

FIG. 12.—A double-boom scraper dredge on rollers.

which swings the load to either side, and when the hauling line is released the scraper dumps automatically. This machine works longitudinally with the ditch and backs away from the work. It has the power to dig hard material, though there seems to be some difficulty in guiding the scraper so as to cut a sloping bank; but some means will no doubt be devised to overcome this fault. This scraper is much lighter than any bucket in use holding an equal amount and can therefore be used with a smaller engine, making the machine lighter in construction.

A machine of the scraper type that has been used to some extent in Illinois, Iowa, and Minnesota is shown in figure 12. It is mounted on a

platform which moves on rollers ahead of the work, so that no weight is placed on the berm of the ditch after its construction, which is an important matter where the ground is soft and has a tendency to cave. The novel feature of this machine is that it has two booms projecting out in front. They are set apart at the foot, according to the width of the ditch to be cut, and swing from the center of the ditch outward. The point of the boom is raised and lowered with the scraper and the operations are so timed that one scraper is being discharged while the other is being filled. This gives the machine a greater capacity than it would have with one boom, and the method of setting the booms apart gives them a longer reach than a single boom of the same length pivoted at the center. The machine is so constructed that it automatically cuts a uniform slope and width of the bottom, both of which are easily and quickly changed. This adjustment enables the same

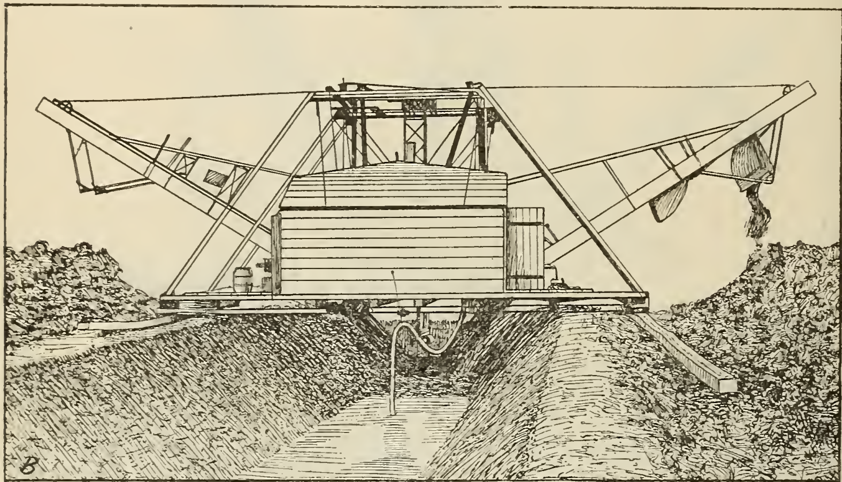

FIG. 13.—Front view of a scraper dredge on track.

machine to cut a bottom ranging from 3 to 20 feet, which is a desirable feature where the ditches in any one project are of different sizes.

The machine makes a neat, smooth slope and a uniform grade, but for some reason it has not come into general use. Like all other traction or roller machines, it is more difficult and expensive to operate where the ground is marshy or covered with water or where it is uneven and cut up with old channels and surface ditches. Under these conditions it is necessary to block or bridge across the depressions and lay heavy timbers on which to move the dredge. Where the machine is large, weighing upward of 30 tons, this becomes a matter of considerable expense and often makes it more practicable to use a floating dredge.

Anotner type of scraper dredge (figs. 13 and 14) is constructed on an entirely new and original principle. It is usually built to travel on a

track with one rail on each side of the ditch and is propelled by traction. It can work either upstream or down, and no water is required in the ditch for its successful operation. The excavating scrapers, two in number, are connected by a bar, backs toward each other, and travel in the guide frame transversely to the line of the ditch and shave off a thin slice down one side across the bottom and up on the opposite side, one scraper cutting when going one way and the other in the opposite direction. The frame carrying the scrapers is lowered automatically as the ditch increases in depth, so that the banks and bottom are cut to exact specification. When the required depth is reached the guide frame is raised and the machine moved forward or backward the required distance and the operation repeated.

This machine has passed the experimental stage and does excellent work where the conditions are favorable for its operation. The ditch

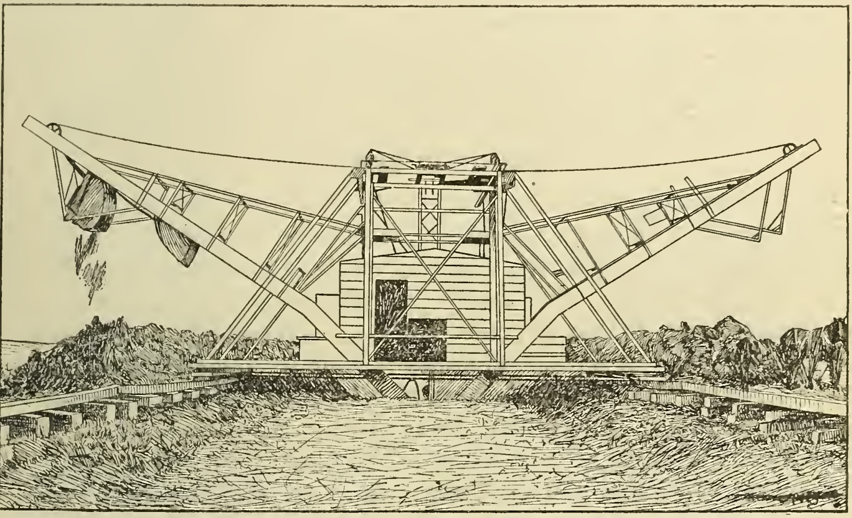

FIG. 14.—Rear view of a scraper dredge on track.

it makes is mechanically perfect, being cut from the natural earth with perfectly sloped banks and a true grade. By beginning at the outlet and working upstream so as to draw off the surface water it can be used in very soft ground. It is not, however, suited for digging ditches in timbered lands or where there are roots, stones, or other obstructions.

ELEVATOR DREDGES.

Another type of machine, known as the elevator dredge, has been used to some extent for digging ditches and building levees. The material is excavated by a series of scrapers, each holding from 3 to 15 cubic feet, attached at intervals of 3 to 6 feet to two endless chains that run on sheaves at each end of a framework called the ladder. One end of this framework is pivoted to the barge or frame of the car

and the other end is suspended from an A-frame in such a way that it can be raised and lowered at will. Power is applied by an engine to a shaft through the ladder, driving the chains to which the buckets are attached. The buckets as they pass around the ladder scrape the material from the bottom and front of the excavation and bring it upon deck, where it is discharged on either side by means of a traveling belt conveyor, or is carried to an elevated hopper by a bucket elevator, and mixed with sufficient water to discharge it through spouts or troughs to the desired point. In some instances the heel of the ladder is pivoted so that it will rotate about a center, while in others it is fixed rigidly to the boat and a horizontal movement is secured by swinging the front end of the hull about a center spud as a pivot.

The results obtained by machines of this type in ditching and levee building do not entitle them to much consideration. They are cumbersome in their construction, very difficult to keep in repair, and will work only in soft material free from roots, stones, and other hard substances. The buckets take up a great deal of water with the earth, and in whatever way discharged it runs and spreads over a large surface, making it objectionable either for ditching or levee building.

HYDRAULIC DREDGES.

The remaining type of machine to be described is a hydraulic or suction dredge, as it is often called. The essential parts of a machine of this kind are a centrifugal pump and the power to drive it, all mounted on a barge. The suction pipe is attached to the pump with a movable joint, so that the outer end can be raised or lowered to the required depth. A horizontal sweep is usually obtained by swinging the hull of the dredge from side to side by means of lines attached to anchors on shore. A hydraulic dredge is the most economical machine for excavating material that is easily displaced and conveying it long distances. The solid matter is taken up in suspension with the water and can be discharged through pipes several thousand feet long. Coarse sand and gravel, muck, and silt are easily handled in this way, and by the use of a rotary cutter on the end of the suction pipe comparatively hard clay can be removed. It does not work well, however, where there are stumps, stones, logs, or other obstructions. Dredges of this type are not well suited for ditching or levee building, but are well adapted for filling tidal flats and lowlands that are surrounded by an embankment. Much land on both the Atlantic and Pacific coasts has been reclaimed and made habitable by this method. For removing sand bars in navigable streams and for dredging sand for commercial purposes there is nothing better than the hydraulic dredge.

There are some other types of dredges built, but, as they have not come into general use and do not give promise of any special advantages to recommend them for ditching or levee building, no description of them is given.

DITCHING WITH A DREDGE.

Seagoing dredges and those that can be towed safely on open water are, as a rule, too large to be used for ditching purposes, so in nearly all cases it is necessary to build a dredge on the land to be drained. The traction machines in use when set up ready for operation are also too heavy to be loaded on a car and transported from place to place. They are shipped knocked down, and it requires several weeks' time and heavy expense to set one up ready for work. In any project the outlay in getting the machine on the ground ready for use must be added to the operating expenses to ascertain the entire cost of the work. This expense is so great that unless there is a large amount of excavation, 60,000 cubic yards or more, that can be handled with one setting of the machine, it is not feasible to use one. For this reason it is highly advantageous for landowners to cooperate in planning drainage systems so as to include as much work as possible in one project. Where a drainage canal is 6 miles long it is perfectly feasible to secure a dredge to do the entire work, whereas it would be too expensive to secure one to do but 2 or 3 miles.

Many of the States have general drainage laws providing for the organization of drainage districts to enable landowners to unite in reclaiming large areas of swamp land. If two or more ditches are to be constructed in one district, they should be connected or so arranged that the machine can be readily moved from one to the other without dismantling. This will save time and reduce the expense of the work. It should be borne in mind by those interested that the larger the amount of connected work included in any one project the less it will cost per cubic yard to do the work with a dredge.

TYPE OF DREDGE TO SELECT.

Where the amount of work is sufficient to justify the use of the dredge, the next question to determine is the kind of a machine best suited for that particular work. The amount of water on the ground, the size of the ditches, and the character of the material to be excavated are the conditions that largely determine this matter. If the land to be drained is covered with water and is of a boggy nature, or if the ditch follows an old stream that is to be cleaned out, widened, and deepened, a floating dredge of some kind is best suited for the work; on the other hand, if the surface of the ground has little or no water on it, and is comparatively smooth and firm, a traction dredge should be used. If the ditches have a top width of less than 16 feet, they will be too narrow for a floating dredge, and some other type should be used. Where the work is on land containing many stumps or buried logs, or in hard clay, or in clay and bowlders, a dipper dredge should be used.

Some types of machines make more accurate grades and side slopes

than others, which should be taken into consideration when selecting a machine, although there is a difference of opinion among drainage engineers as to how much weight should be given to this feature. Not only the cost of the ditch, but the expense of maintaining it in good condition should be considered in deciding on its form and the methods of constructing it. If a ditch with a perfectly true grade and accurately sloped banks will retain its shape better and require less frequent cleaning, then it is worth more to the landowner, and a machine that will cut such a ditch, other things being equal, is a more desirable one to select. It is well known that neither a dipper dredge nor a clamshell will cut a true grade or an accurate slope. The sides are rough and irregular, varying from ½ to 1 horizontal to 1 perpendicular, with a variation in grade of from 3 to 12 inches. Dredge operators attempt to compensate for the irregular and rough channel by digging the ditch wider and deeper than the specifications require. They claim by doing this that the channel has a greater capacity, and should it fill in the low places it would still be worth more than if cut to the exact dimensions specified. On the other hand, the manufacturers of machines of the scraper type, which do more accurate work than dipper or clamshell dredges, claim that a ditch cut to the exact line and grade makes a more permanent waterway and offers less resistance to the flow of water in the channel. Much can be said on both sides of this question, but numerous and long-continued observations have led to the conclusion that where there is sufficient discharge to require a ditch large enough to permit the use of a floating dredge it matters but little whether or not the banks are smooth and have a uniform slope. Natural streams of much depth nearly always have irregular banks with little slope, and when kept free of obstructions, such as fallen timber, brush, fences, etc., they retain their shape permanently.

At least 90 per cent of the machine-constructed ditches in the United States has been made with the floating dredge, and the behavior of these ditches warrants the conclusion that in most soils a drainage ditch cut with a floating dredge will, by the process of erosion and scouring, acquire within a year or two a uniform grade with a slightly rounded bottom and smooth firm banks, having a slope of about one-half horizontal to 1 perpendicular. This form of ditch has the least wetted perimeter, which is conducive to a maximum flow and is eminently satisfactory for large channels.

Where the ditches are small (3 to 8 feet wide on the bottom), are made deep to provide outlets for tile drainage, and seldom flow more than one-third full, the grade, slope, and smoothness of the sides are essential matters. Under these conditions there will not be water enough to wash out the loose material that gets in, and, the ditch being dry the greater portion of the year, vegetation will spring up

particularly on the slope near the surface, and if not removed will fall in and obstruct the flow. Such ditches should have narrow bottoms on a true grade, and have bank slopes of $1\frac{1}{2}$ horizontal to 1 perpendicular, as smooth as can be made with a machine. A ditch of this form will confine the flow to a narrow space and thus increase the depth, giving a greater velocity. The side slopes above the water line can be seeded to grass, which can be kept closely cut. For digging ditches of this kind a dry-land machine of some type must be used.

Another element that enters largely into the maintenance of a ditch is the width of the berm. More injury has been caused to new ditches by placing the material excavated too near the edge than from all other sources combined. There should in all cases be a clear space of at least 6 feet between the edge of the ditch and the toe of the spoil bank. In deep cuts, especially where the amount of excavation is increased and the ditch banks are required to sustain a greater weight, this should be increased. In practice, however, the opposite is usually done. The dredge is built to have the necessary reach on level ground, and where a deep cut is encountered the excavated earth is piled close to the edge of the ditch, causing disastrous caving. To avoid this a longer boom should be used or the material excavated should be moved back by other means. Along a ditch through cultivated lands it pays to level the large unsightly waste banks left by a dredge so that the land may be available for crops.

One machine may be secured on more liberal terms or for a less price than another, may cost less to operate or be more durable, and these things should be taken into account in deciding upon the dredge to buy, but adaptation to the work to be done should be given first consideration.

COST OF DREDGES.

The cost of dredges varies as much as the cost of houses, so no definite information can be given on this point. The size or capacity of the machine is the most important element in determining its cost. A $1\frac{1}{2}$-yard dredge usually costs more than a 1-yard dredge, and a 2-yard more than a $1\frac{1}{2}$-yard, yet the details of the construction, the quality of the material to be used, and the place where it is to be erected have much to do with the price. The machinery and ironwork are usually made at the shop of the manufacturer, while the lumber for the hull or platform is purchased in the market and shipped to the place of erection, where it is framed and assembled. The grade of lumber used, the freight rate, the cost of hauling the material and machinery from the railroad to the place of erection, the local price of labor, and the convenience for housing and feeding the workmen are elements which enter into the cost of a machine of any type. It requires at least two cars to transport the material for a small dredge, while for a machine of large size four to six cars are required. After the material

is on the ground it takes from four to six weeks to erect it and install the machinery ready for operation. In some of the traction and roller machines the entire framework is made of steel shapes, gotten ready at the shop and shipped in a knocked-down state to their destination. These can be erected in about two weeks.

At the present time the price of a 1-yard dipper or clamshell dredge erected ready for operation ranges from $5,000 to $7,000; a 1½-yard dredge will cost about $10,000, while a first-class machine of 2-yard capacity will cost upward of $12,000. These figures are given to indicate the general range of prices on dredges suitable for ditching or levee building and will be modified by local conditions.

When a ditch or levee is completed it is in most cases necessary to take the dredge to pieces, in order to move it to another job. The expense of this is 30 to 50 per cent of the cost of a new machine, and it takes from two to six weeks—depending on transportation facilities and distance to be moved. This cost of moving and setting up on a new piece of work and the deterioration of machinery from the natural wear and tear make the price of a second-hand dredge about one-half that of a new one.

METHOD AND COST OF OPERATING A DREDGE.

The better way of operating a floating dredge is to begin at the upper end of the ditch and work downstream. If there is not sufficient open water into which the hull may be launched when it is built, a pit must be dug by hand for this purpose, or a temporary dam placed in the stream below to raise the water high enough to float the dredge. The depth required will vary from 2 to 2½ feet, according to the dimensions of the hull. In some places it is impossible to get the heavy machinery to the source of the ditch, on account of the swampy condition of the ground, in which case it may be built at the most convenient point on the line of the ditch and operated upstream. Where there is but a slight fall per mile this plan is perfectly feasible, but where there is but little water and a steep grade it is slow and expensive. The water is removed from the surface and flows off through the ditch, making it necessary to maintain dams behind the dredge and oftentimes to supply water with a pump to float the machine. In working downstream the ditch remains full and the dredge floats high, so that the ditch bottom can be made narrower than the dredge hull if desired. Moreover, in operating a floating dredge of any kind, a great deal of earth washes off the bucket as it is being raised from the water, and if working downstream this settles in front and is removed as the cut is completed, while if working upstream it is carried under the dredge and settles in the channel. Unless the grade is very slight, less than 1 foot per mile, and there is an abundance of water, the work should be so arranged that it may be prosecuted downstream.

With a drag boat or traction machine it is better to commence at the outlet and work upstream. This draws off the surface water and makes more firm the ground on which to lay the track and has the further advantage of enabling the operator to see his work, so that he can make a better finished slope and grade. Usually there is not sufficient water to carry the waste that falls from the bucket back behind the machine so as to fill the ditch. Another advantage in commencing at the outlet is that the landowner gets the full benefit of the ditch as fast as it is constructed. He can ditch into it and drain the adjacent lands, whereas if dug with a floating dredge it would remain full of water for a considerable length of time, during which it would be of little use as an outlet.

The dredge being provided, the next step is to clear the right of way. Where there is timber along the line, for 50 feet on each side of the margin of the ditch it should be cut close to the ground and removed. In doing this everything suitable to burn can be cut into proper lengths and piled convenient to the work to be used as fuel on the dredge. In many places the wood thus obtained will practically pay for clearing the right of way of the ditch. Oftentimes the trees are felled and left to be removed by the dredge, but this is poor policy, as not only is the value of the wood lost but the expense for the time of the dredge and crew consumed in doing such work would much more than pay for the labor of doing it.

Although a dipper dredge is effective in digging stumps, it greatly expedites the matter to use enough dynamite to shatter them or blow them out entirely. This not only effects a saving of time but reduces the liability of breaking the dredge. With a clamshell or scraper dredge it is necessary to remove all stumps over 8 inches in diameter in order to make even fair progress with the machine.

An engineer, a cranesman, a fireman, and a deckhand are required to operate a dipper dredge, and on their skill and efficiency depend largely the cost of doing the work. The engineer in charge should be a man of judgment and experience, energetic and willing to work. His duties, though not hard, are exacting and call for the exercise of sound judgment and discretion. It requires natural adaptability to become a skillful operator, and the details of the business can be acquired only through years of experience. The wages usually paid an engineer range from $3.50 to $5 per day. The duties of the other men of the crew are not so important and can be performed by any good laborer. Their wages depend upon the locality in which the work is done and the scarcity of labor, and range from $1.25 to $3 per day.

The amount of fuel consumed on a dredge depends largely upon the size and type of boiler used. On a 1-yard dredge with a locomotive fire-box boiler about 1 ton of bituminous coal or 2 cords of common wood will last a day of ten hours.

There are a great many breaks on a dredge, and the bill for repairs is much more than for any other kind of machinery. This is particularly true where there are many stumps or much hard material to be removed. Because of the sand and grit found in the soil, the wear and tear on the bucket and cable sheaves is a heavy expense that can not be avoided. The best that can be done is to have them so constructed that the wearing parts can be readily renewed.

The cost of operating a 1-yard dredge of any modern make is about as follows:

Daily cost of operating 1-yard dredge.

	Cost per day.
1 engineer, who acts as foreman	$4.00
1 cranesman	3.00
1 fireman	2.00
1 deck hand	1.75
1½ tons low-grade coal (or equivalent)	6.00
Oil, waste, and repairs	2.00
Total	18.75

Dredges are usually operated day and night, and the expense of the second shift would be about the same, making a total for twenty-four hours of $37.50.

Most dredge ditches are in sparcely settled districts, so that it is necessary to provide subsistence for the operating crew, which adds to the cost per day: For 1 cook $1, and for provisions for 7 men $3.50, thus making the total daily expense for a double shift $42.

The output of the dredge depends mainly on two things, the efficiency of the management and the character of the work. Where the material is muck, loam, or soft clay free from stumps or logs, a good 1-yard dipper dredge will excavate in a double shift an average of 1,000 cubic yards per day for the season's run, making a net cost of 4.2 cents per cubic yard. In hardpan or quicksand 600 yards would be a good output for the two shifts, making the cost 7 cents per yard. It is difficult to estimate the cost of dredge work in a heavily timbered swamp, as breakdowns and delays are frequent and expensive. It is common in practice to estimate one yard in timber equal to two in open country.

THE OWNERSHIP AND OPERATION OF DREDGES.

Operating a dredge is like any other business—one person succeed where another fails, under the same conditions. It is easier to figur out a low cost of excavation on paper than to secure it in actual work There are many drawbacks, such as inclement weather, caving banks beds of quicksand, sunken logs and submerged stumps, poorly planne and defective machinery, bad water for boilers, labor strikes, an unforeseen accidents that oftentimes materially increase the cost of th work.

Where a landowner has many thousand dollars' worth of work to be done and is able to give it his personal attention, it is cheaper for him to purchase a dredge and do his own work, but where the amount of excavation is comparatively small, and the owner's time is taken up, or he is not convenient to the work, it is advantageous to let the job by contract to some one equipped for doing it. In this case complete plans and specifications should be prepared by some competent engineer and the contract let at a fixed price per cubic yard or per mile for the finished work. One provided with a dredge and skilled in the business of dredging can do the work at a less cost than the landowner and still make a profit.

In drainage districts there is a lack of centralization of authority that makes it undesirable for the persons interested to undertake to own and operate dredges. The drainage commissioners, as a rule, are poorly paid, have their own business to attend to, and are inexperienced in the dredging business. As a rule they can serve their districts better by letting the contract to some responsible person equipped for doing the work and supervising the construction. In most places where drainage districts have purchased dredges and attempted to do their own work the results have not been satisfactory. It usually costs more than they had anticipated and frequently causes dissatisfaction among the taxpayers of the district.

THE NEED FOR A SMALL MACHINE.

There is a great demand for a small portable machine for cutting ditches 2 or 3 feet wide on the bottom and 3 to 5 feet deep. Such a machine, if made so that it could be readily transported from one farm to another, would be of great assistance, even if its daily capacity was not large. Many inquiries are received asking if there is such a machine on the market, but there appears to be nothing that meets the requirements. In digging irrigation ditches and in draining the salt marshes along the Atlantic coast there is a great deal of work for such a machine.

MACHINES FOR LEVEE BUILDING.

In certain sections of the country earthen embankments or levees are necessary to protect the low lands from overflow. In some places they are but 3 or 4 feet high with narrow bases, while in others, as along the lower Mississippi River, they are ofter 20 feet high, with bases more than 100 feet wide. Formerly this work was all done with teams and scrapers, or with wheelbarrows, but recently much of it has been done with dredges with very gratifying results. Where the levees are small a floating dipper dredge does good wook; but for levees with large cross sections containing 1,000 or more cubic yards per station of 100 feet the reach is not sufficient, and it digs a pit too

near the base of the levee for safety. Several attempts have been made to build dipper dredges with long booms for building levees, but they have not proved successful. A clamshell dredge, however, overcomes the difficulty, as a very long boom can be used. A number of such dredges are in operation in Louisiana with booms ranging from 90 to 120 feet long.

Where the surface of the land is free from water an increased advantage may be secured by using a machine that runs on a track. In this way the material may be taken from one side and deposited on the opposite side, while with a floating dredge the earth must be taken in front of the machine and placed on the side (fig. 15).

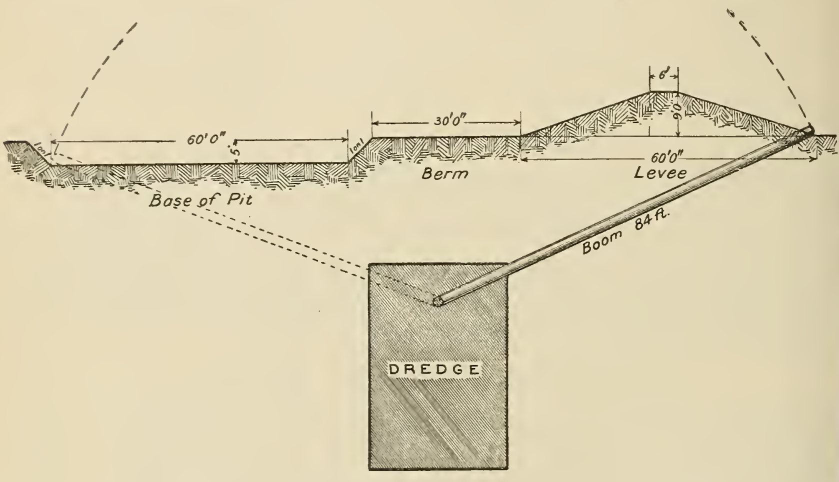

FIG. 15.—Sketch showing position of traction dredge in levee building.

The cost of building a levee by means of a dredge is less than one-half that by wheelbarrow or team and scraper. The following figures, taken from actual practice, show the cost of constructing a levee in alluvial soil where there is no clearing to be done with a modern traction dredge operating a 2½-yard orange-peel bucket:

Cost of building levee with traction dredge.

1 engineer, at $120 per month	$120.00
1 fireman, at $50 per month	50.00
1 track foreman, at $2 per day	52.00
4 trackmen, at $1.75 each	182.00
1 pumpman, at $1.50 per day	39.00
Monthly wages for one shift of 11 hours	443.00
Same for night crew	443.00
1 team and driver hauling coal for both shifts	91.00
1,040 barrels Pittsburg coal, at 37 cents	384.80
Oil and waste (estimated)	10.40
Repairs and breakage	78.00
Operating expenses for one month	1,450.20

The amount of earth moved by this dredge varies from 32,000 to 46,000 cubic yards per month, with an average of probably 38,000 yards, making a cost of 3.8 cents per yard for handling it. To this must be added 1.5 cents per cubic yard for dressing the slopes and sodding the banks after the material is in place, making the actual cost of the levee 5.3 cents per cubic yard. The cost herein given, both for ditching and levee building, is that secured in actual practice by an experienced contractor under the most favorable conditions, and any one without experience engaging in the business will encounter many adverse conditions and in a season's work will find that the cost will greatly exceed the figures here given. This will result not so much from an increase in the operating expenses as from a decrease in the output of the dredge, owing to the fact that it could not be kept running constantly. As in ditching, competent and close supervision has a great deal to do with the expense of operation; and the kind of material to be excavated, and the character of the surface over which the machine has to be moved, affect largely the cost of building levees with a dredge.

A machine-made levee is better than one made by wheelbarrows and is as good as one built with teams and scrapers. The dirt is taken up in large quantities and falls with considerable force, which compacts it as it is placed in the levee. In selecting a machine to build levees the one that takes up the least amount of water with the material will be found most satisfactory. If the earth is too wet, it will not stand at the required slope, making it necessary to go over the work more than one time. This can be readily done with a floating dredge, but is impracticable with a traction machine of any kind.

Attempts have been made to build levees with both elevator and hydraulic dredges, but they are not adapted to this kind of work. They discharge so much water with the material that it is hard to hold it in place and keep it from overrunning the base of the levee. By throwing up two parallel ridges of turf or dry material to form the toe of the slopes the wet material can be held in position until it solidifies, and another layer can be put on in the same manner until the desired height is reached. This method of construction makes a good levee, but the hand work required to build the retaining ridges makes it expensive. The hydraulic dredge has, however, one advantage not possessed by other machines for levee building: The material may be carried through pipes a long distance (a thousand feet or more) and deposited in front of the dredge or behind it, while with the other machines the earth must be deposited opposite the place from which it is taken.

MACHINE FOR TILE DITCHING.

Several attempts have been made to build a machine suitable for digging small ditches for drain tile, but so many difficulties were encountered that most of the efforts have not gotten beyond the experimental stage. There is, however, one machine that has been sufficiently tried to demonstrate its efficiency under certain conditions. A strong, rigid frame carrying the engine and boiler and such auxiliary machinery as is necessary is mounted on wheels and so geared to the engine as to be self-propelling. The tires of the wheels are very broad and present sufficient surface to carry the machine over soft ground without the aid of a track, and with the aid of plank laid down to make a platform to support the machine in case of very swampy land it can be used on any land that will sustain the weight of a man. The gears that drive the machine are of different sizes, and any speed desired may be secured by inserting different-sized gears.

The digging is done by an excavating wheel constructed of malleable iron and steel with two circular rims held together at a proper distance from each other by the steel buckets rigidly riveted in place. This wheel is carried in a frame, one end of which is hinged to the platform of the car, the other resting on the wheel itself and a leveling shoe which slides along in the bottom of the trench, thoroughly leveling the little inequalities which are occasioned by the vibration of the machine and by obstructions taken up from the bottom.

The wheel is about 9 feet in diameter and is driven by power applied to the rim rather than to the axis on which it is built. This arrangement greatly decreases the power necessary to do the cutting. On the periphery of this wheel are 12 or more buckets, whose cutting edges are semicircular in shape. A little ahead of these are placed side cutters, two to each bucket, one on each side. They are so inclined that their cutting edges alone come in contact with the earth, thus reducing the friction to a minimum. The wheel being driven directly above the point where the actual cutting is being done, there is but little lost power. This wheel can be so raised or lowered by the operator as to cut to the proper depth, and the speed at which it moves forward is regulated by the number of teeth in the traction gear in use. The excavating wheel is driven by two heavy sprocket chains by power taken from the engine on the main platform. The earth is shaved from the ditch (see fig. 16) by the buckets and carried up toward the top of the wheel and is deposited on a carrier of 3-ply rubber belting which discharges it at a safe distance alongside the trench.

To overcome the difficulty encountered where the material is sticky and adheres to the sides of the buckets, two cleaners are provided for each bucket, which scrape the material from the buckets, so that it falls on the carrier. Without these cleaners the machine would not

work in adhesive material, but they are so arranged and controlled by springs that they scrape both back and sides of the buckets and leave them clean, as they return to a cutting position.

By means of targets set ahead of the work and the sight arm on the frame carrying the excavating wheel, a very accurate grade can be cut. The weight of the machine is carried ahead of the ditch, the excavating wheel being behind, so that the danger of caving is lessened. Where the ground is comparatively level and free from heavy obstructions and the ditch ranges from 3 to 5 feet deep, a machine of this type will be found very serviceable and more economical than hand labor. Where the ditches are in short lengths and the surface of the ground is uneven or very soft, much difficulty will be experienced in getting the machine from one ditch to the next, and where later ;

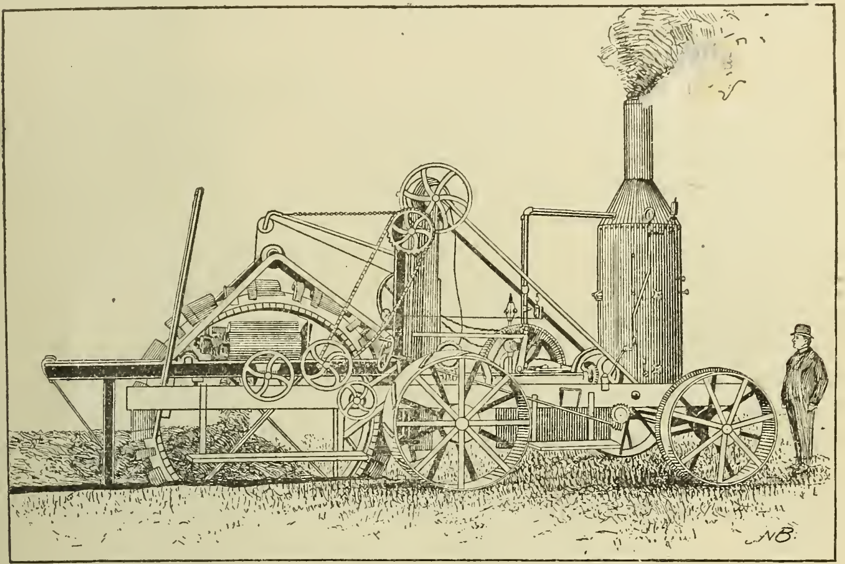

FIG. 16.—Traction ditcher for excavating tile drains.

join a main it is necessary to do some hand work to make proper connections. This machine has been extensively used throughout Illinois, Missouri, and Iowa and is looked upon with much favor. The estimates given as to cost of operation and the amount of work a machine of this kind will do in a day vary greatly with the operators; but under favorable conditions, where the ditches are in long lengths, it will readily make from 70 to 100 rods of ditch 30 to 36 inches deep in a day of 10 hours. As most of its movements are automatic, the cost of operation is comparatively small, not exceeding $10 per day. The machine seems to be well designed, of good material, and under proper management should be operated without much expense for repairs.

CONCLUSIONS.

(1) The only feasible way in which large areas of swamp land can be drained is by the use of a dredge of some kind.

(2) The larger the area to be drained and the greater the quantity of earth to be removed, the less the cost per cubic yard for doing it.

(3) Where there is much water on the surface or many trees and stumps to be removed, a floating dipper dredge is the best for the work.

(4) For very wide ditches, where the material is soft and the banks cave readily, a clam shell with a long boom does the best work.

(5) For small ditches on firm ground some kind of traction machine is best suited.

(6) Machines of the scraper type cut the most accurate slopes.

(7) A floating dredge should commence at the upper end of the ditch and work downstream and a traction dredge should commence at the lower end and work upstream.

(8) When constructing large ditches having water flowing in them the greater part of the year the slope of the bank is not of much importance, as nature will soon make the slope best suited to the soil. In small ditches with water flowing only a part of the time, smooth, sloping banks and a true grade are very essential.

(9) Through heavy timber a right of way at least 100 feet wider than the ditch should be cleared and the timber removed before commencing operations with the dredge.

(10) It is better for drainage districts to let the contract for their work to some one equipped for doing it than to own and operate dredges.

(11) Large landowners who can give the work close supervision can profitably own and operate their own dredges.

(12) The cost of digging ditches with a machine ranges from 3 cents per cubic yard up, according to the kind of dredge, the character of the work, and the efficiency of the management.

(13) A 1-yard or 1½-yard dredge seems to be best suited for ordinary drainage work.

(14) A clam-shell dredge with a long boom is well suited for levee building.

(15) If a dredge is properly designed, well built, and suited to the work to be done, it is an efficient and cheap appliance for digging ditches or building levees.

(16) The hydraulic dredge is not well adapted to ditch and levee construction.

(17) A machine can now be had which will dig from 70 to 100 rods of tile ditch 30 to 36 inches deep in a day of 10 hours at a cost of operation not exceeding $10 per day.

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